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# Primer on Duval Pentagon and Triangle for DGA Analysis

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## 1 Description of Solutions - Mineral Oil Filled

In this article a number in a bracket '[x]' refers to a document in the References section. Dissolved gas analysis (DGA) in mineral oil filled transformers has been widely used to detect incipient faults as related to the levels of certain combustible gases in the oil. There are several methods available commonly used which rely on gas ratios as calculated in references in IEC [1] and IEEE standards [2]. Although there are other diagnostics with paper involvement, those provide additional methods for gases that are not produced by the liquid.
The five main hydrocarbon gases, in the sequence of energy required to produce them, are $H_2$ (hydrogen), $C_2H_6$ (ethane), $CH_4$ (methane), $C_2H_4$ (ethylene), and $C_2H_2$ (acetylene). The relative percentage of each gas is calculated based upon the sum these five gases. Once the relative contribution is found they are plotted on the Duval pentagon 2 per the reference [4] with their associated angle. The cartesian coordinates of each vector permit a graphical presentation of a polygon connecting each point. Using an estimation method, the centroid of the polygon $(C_x, C_y)$ will be used to determine the location associated with a probable fault type.
The Duval Triangle method requires only three of the hydrocarbon gases. As identified in reference [5] the starting triangle uses the high thermal fault and discharge fault gases of $CH_4$ (methane), $C_2H_4$ (ethylene), and $C_2H_2$ (acetylene). When relative gas generation contains the medium and low temperature thermal faults of $H_2$ (hydrogen), $C_2H_6$ (ethane), $CH_4$ (methane), Duval Triangle 4 is used.

## 2 Mineral Oil Analysis

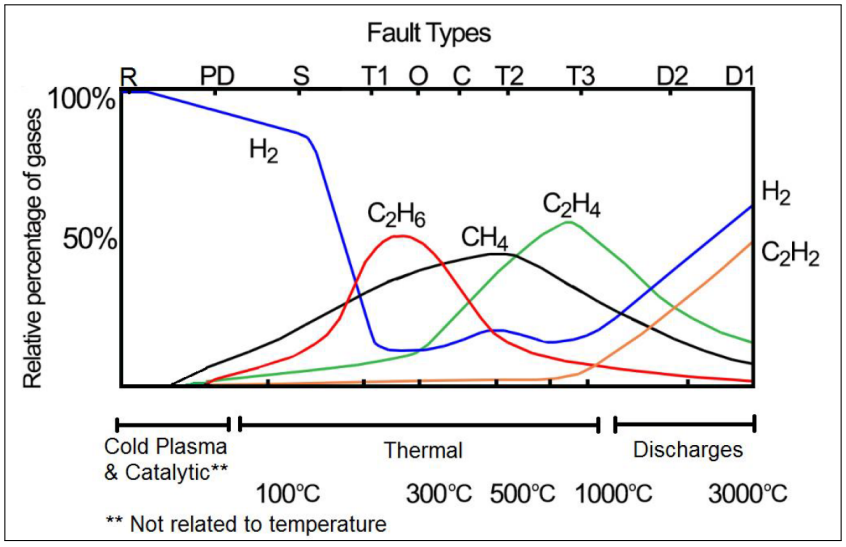


Figure 1: The relative percentage of fault gases are ploted versus the thermal and discharge temperature for mineral oil [5] with the fault type identifiecd.

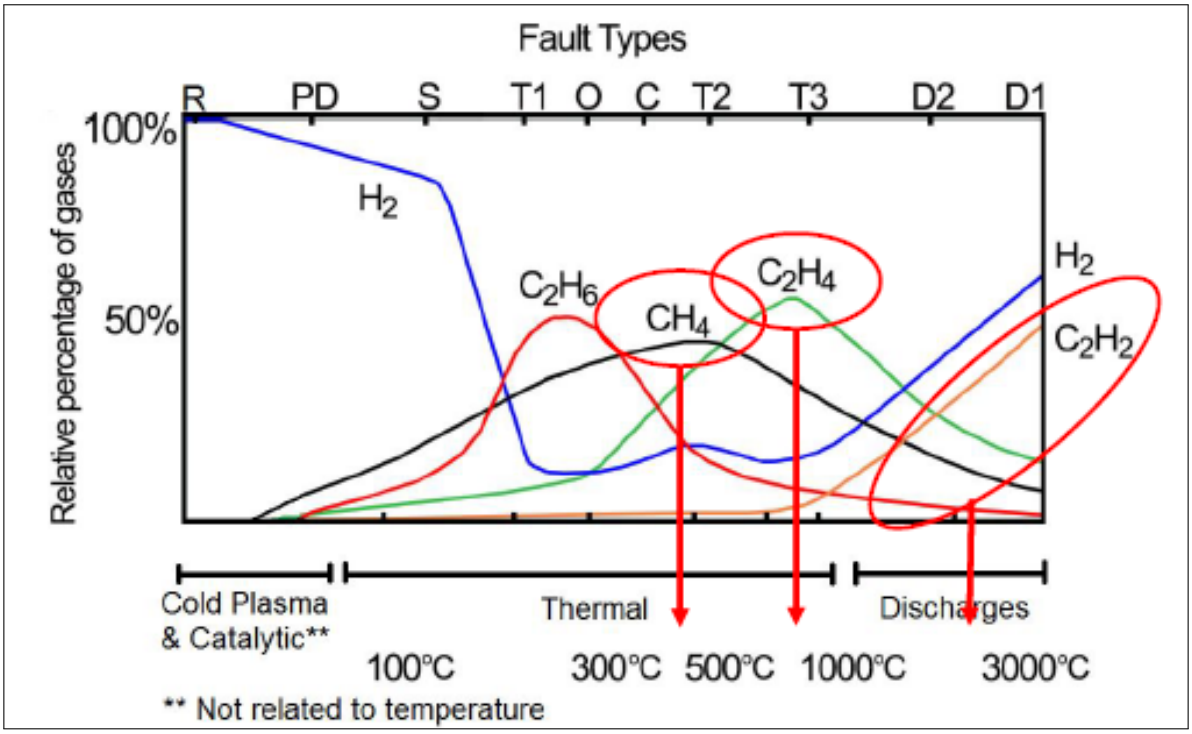


Figure 2: The relative percentage of high temperature fault gases are ploted versus the thermal and discharge temperature for Duval Triangle 1 [5] with the fault type identifiecd.

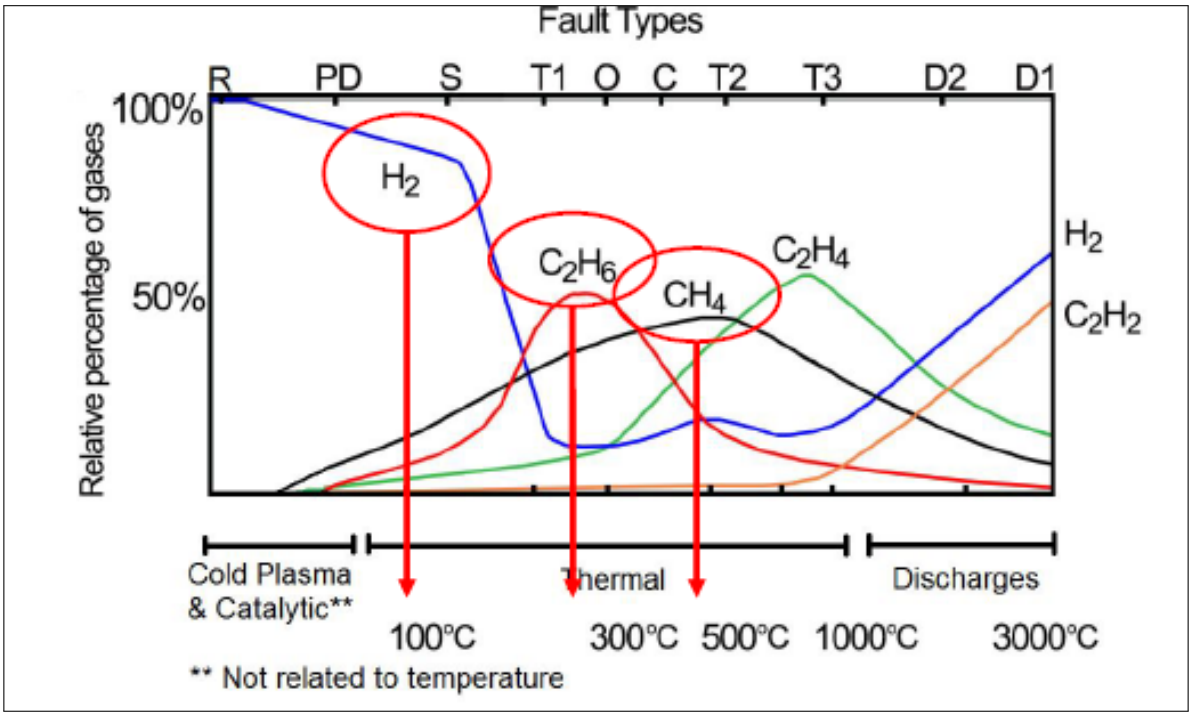


Figure 3: The relative percentage of fault gases are ploted versus the low and medium thermal temperature for Duval Triangle 4 [5] with the fault type identified.

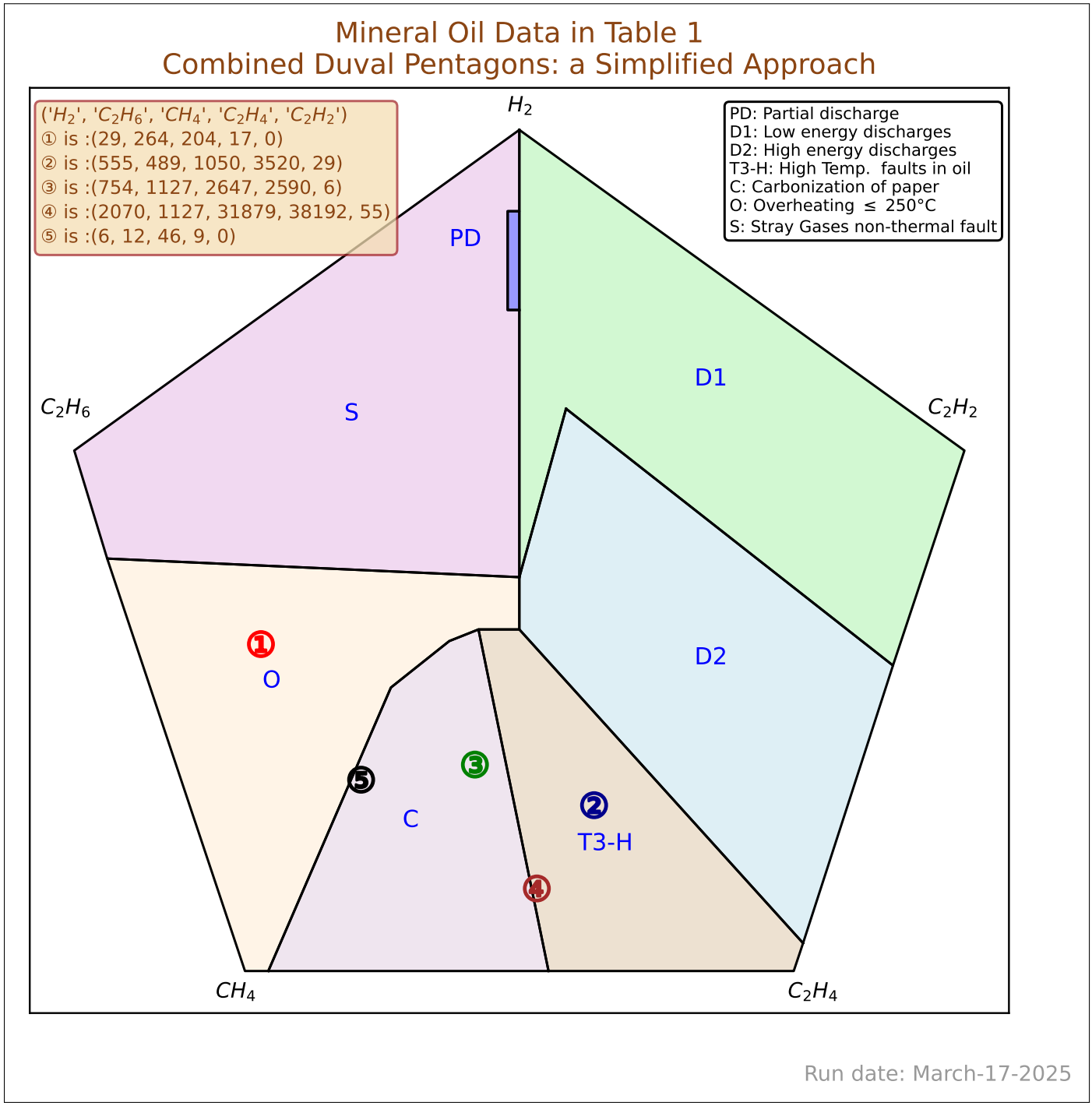


Figure 4: The mineral oil fault zones presented by use of the Duval Pentagon 2 from reference [4] with fault codes identified.

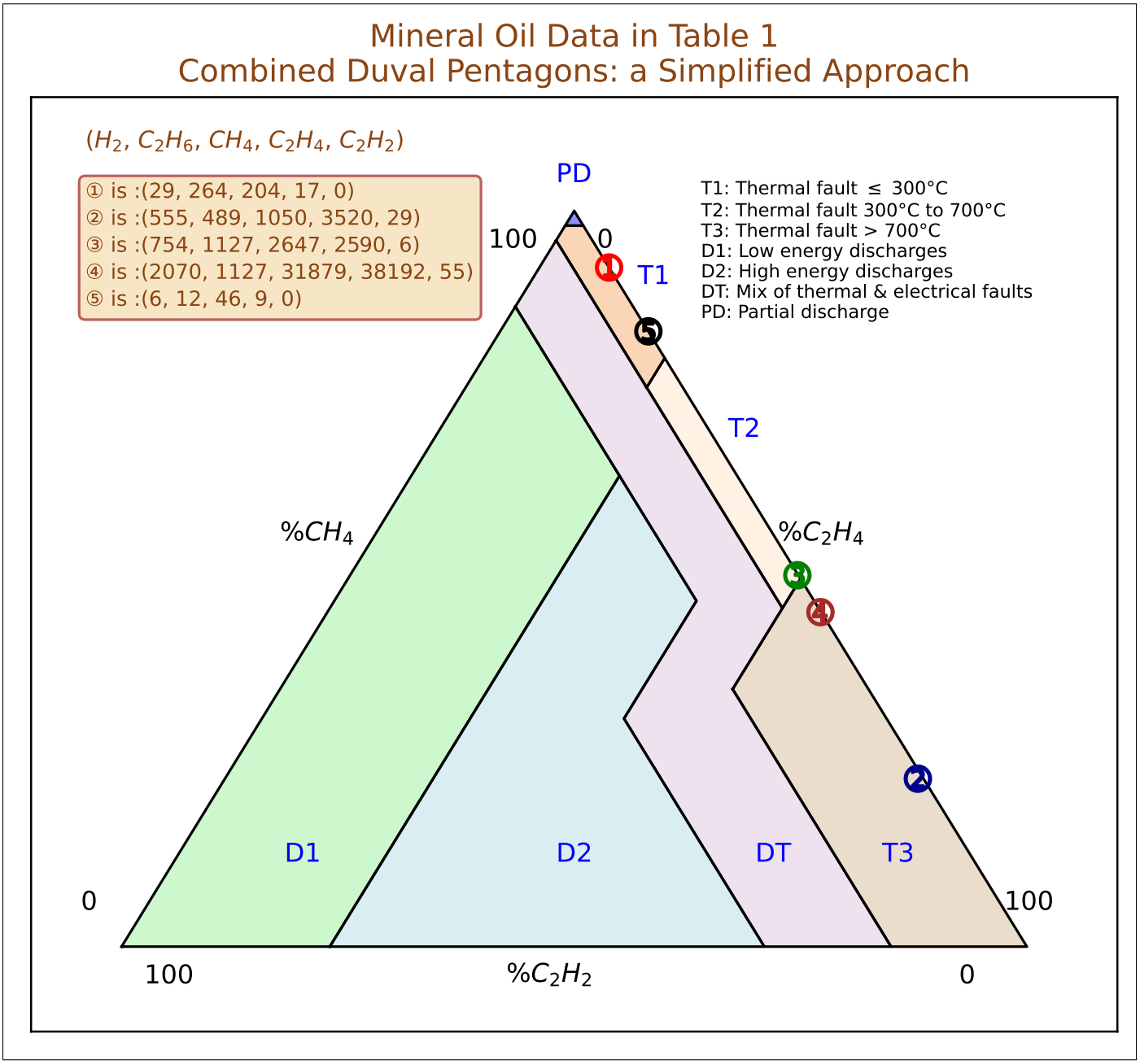


Figure 5: The mineral oil fault zones presented by use of the Duval Triange 1 from reference [4] with fault codes identified.

# 3 Description of Solutions - Ester Filled[3]

The differences between an ester liquid and mineral oil are far greater than the differences between any two mineral oils. Fortunately, the gases generated in ester liquids under fault conditions are the same as those that are generated in mineral oil. However, the ratios and rates of generation can be very different. This at least allows for the use of common methods for sampling and testing.
The difference in the chemical structure of ester liquids leads to important differences in how some gases are produced. Gases produced by the different processes give new or additional meaning to the possible interpretation of DGA results. This means a common method for interpretation of mineral oils data will not work as reliably for ester liquids. Modifications to interpretative methods for mineral oils are necessary for their use with ester fluids.

The most significant differences in gas production for ester fluids are as follows:

1. Ethane produced from non-fault conditions for ester fluids contain linolenic acid.
2. Methane, ethance, and ethylene produced in greater amounts and a lower temperature from overheating.
3. Methane, ethane, ethylene produced in different proportions than mineral oil from overheating.
4. Carbon dioxide and carbon monoxide produced abundantly from over overheating of the ester liquid causes of gas formation.

# 4 Ester Liquid Analysis [6]

## 4.1 Thermal Stress Simulation in Oven

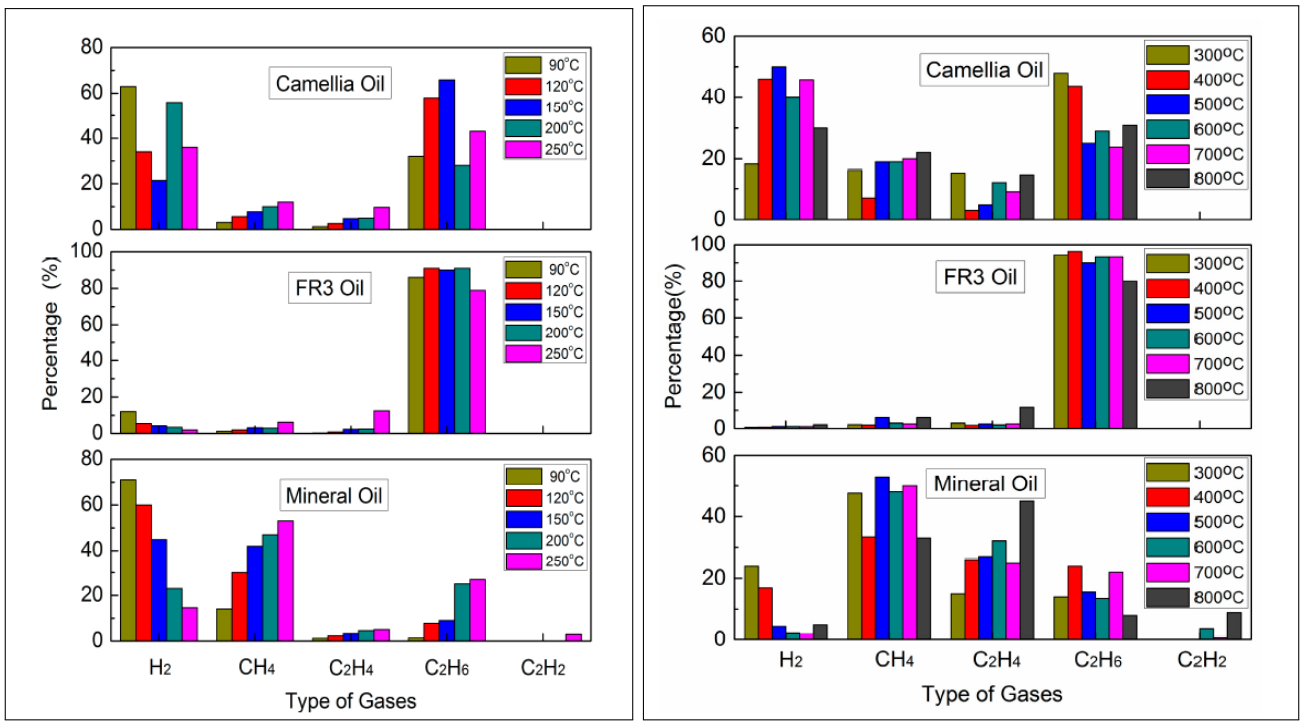


Figure 6: Left graphic is only oil, without paper; Right graphic is a paper oil simulation.

## 4.2 Electrical Stress Simulation

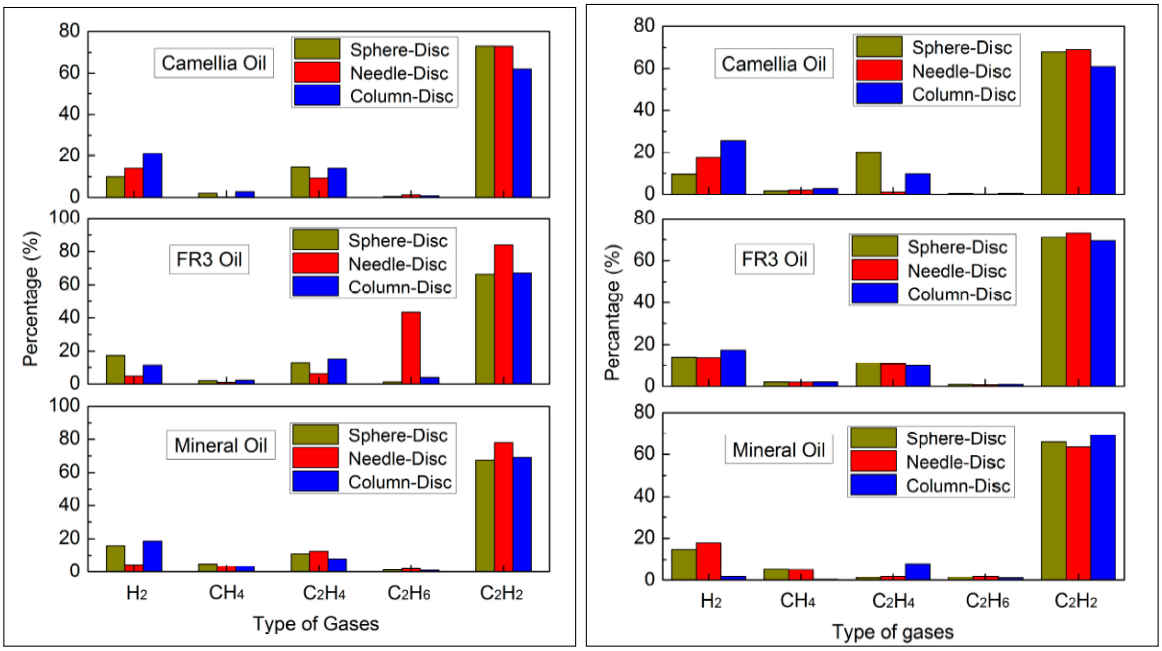


Figure 7: Left graphic is only oil, without paper; Right graphic is a paper oil simulation.

## 4.3 Partial Discharge Simulation

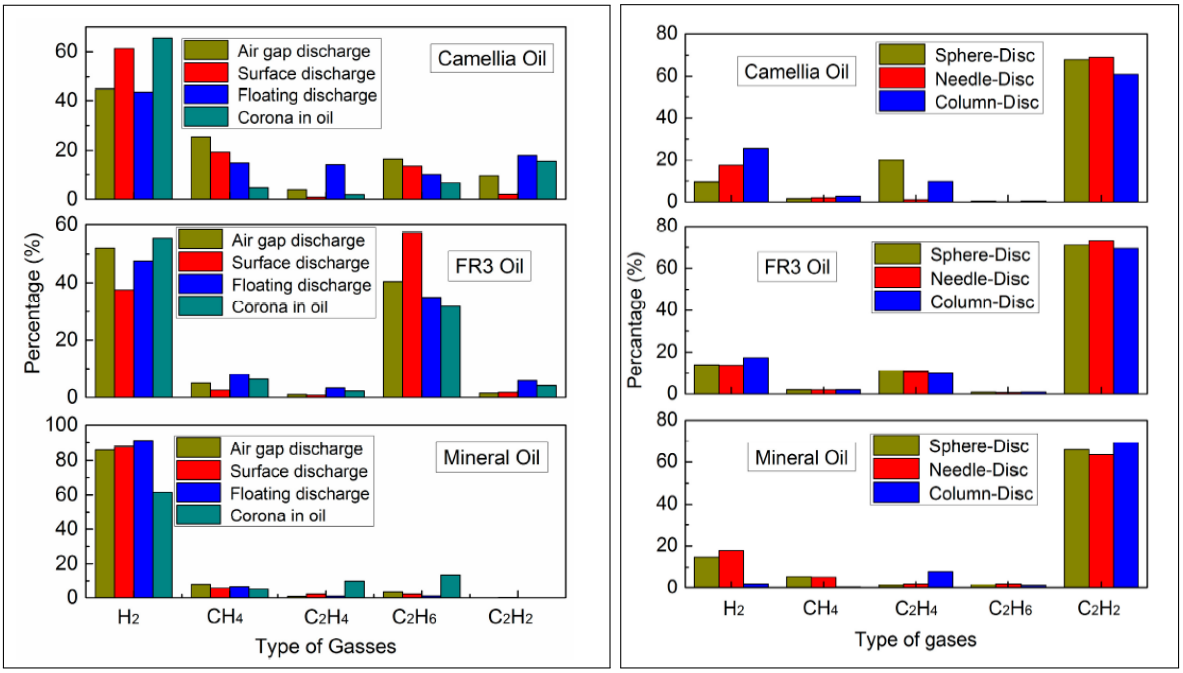


Figure 8: Left graphic is location of discharge; Right graphic is a type of electrode used.

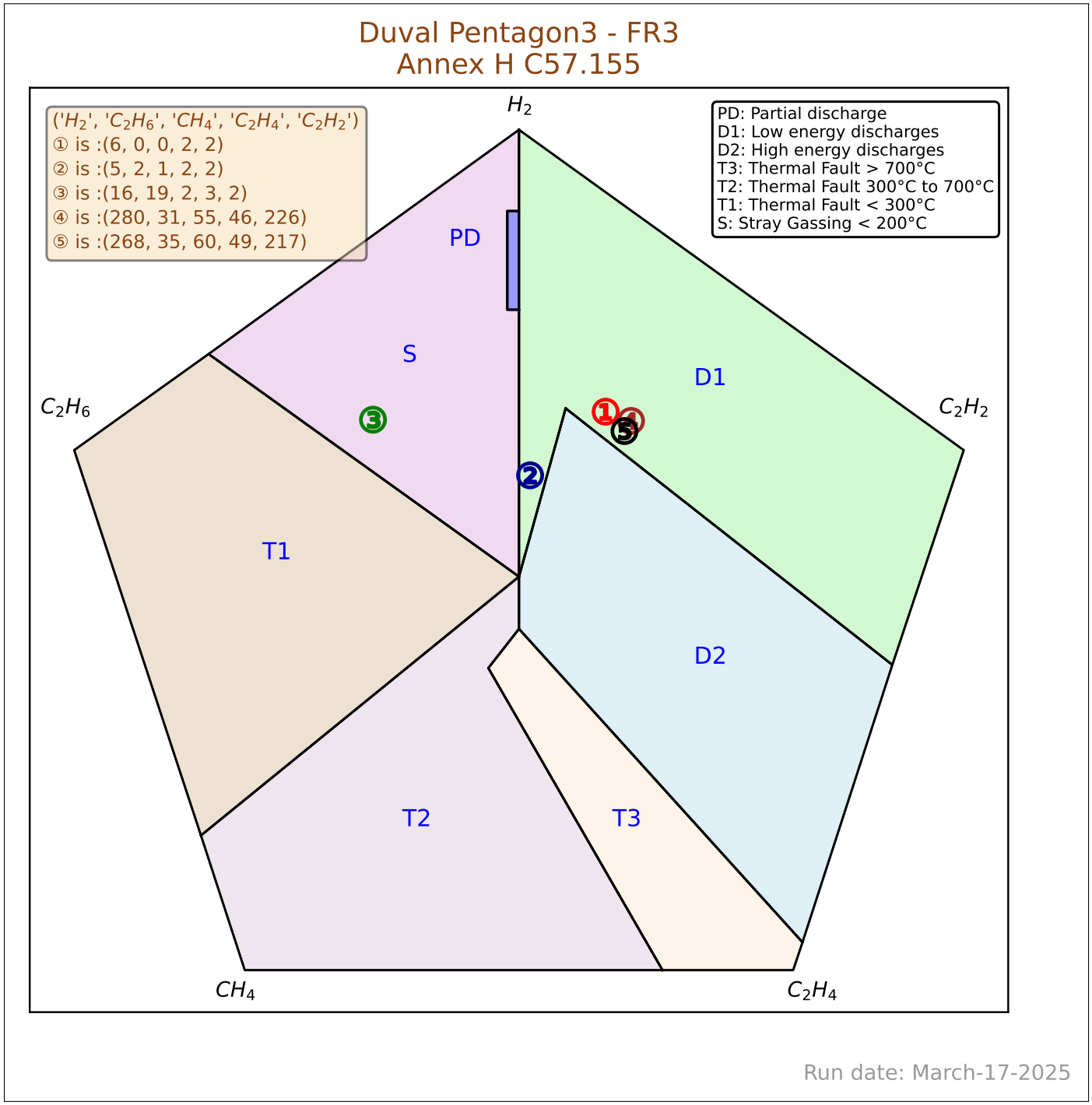


Figure 9: The mineral oil fault zones presented by use of the Duval Pentagon 2 from reference [3] with fault codes identified.

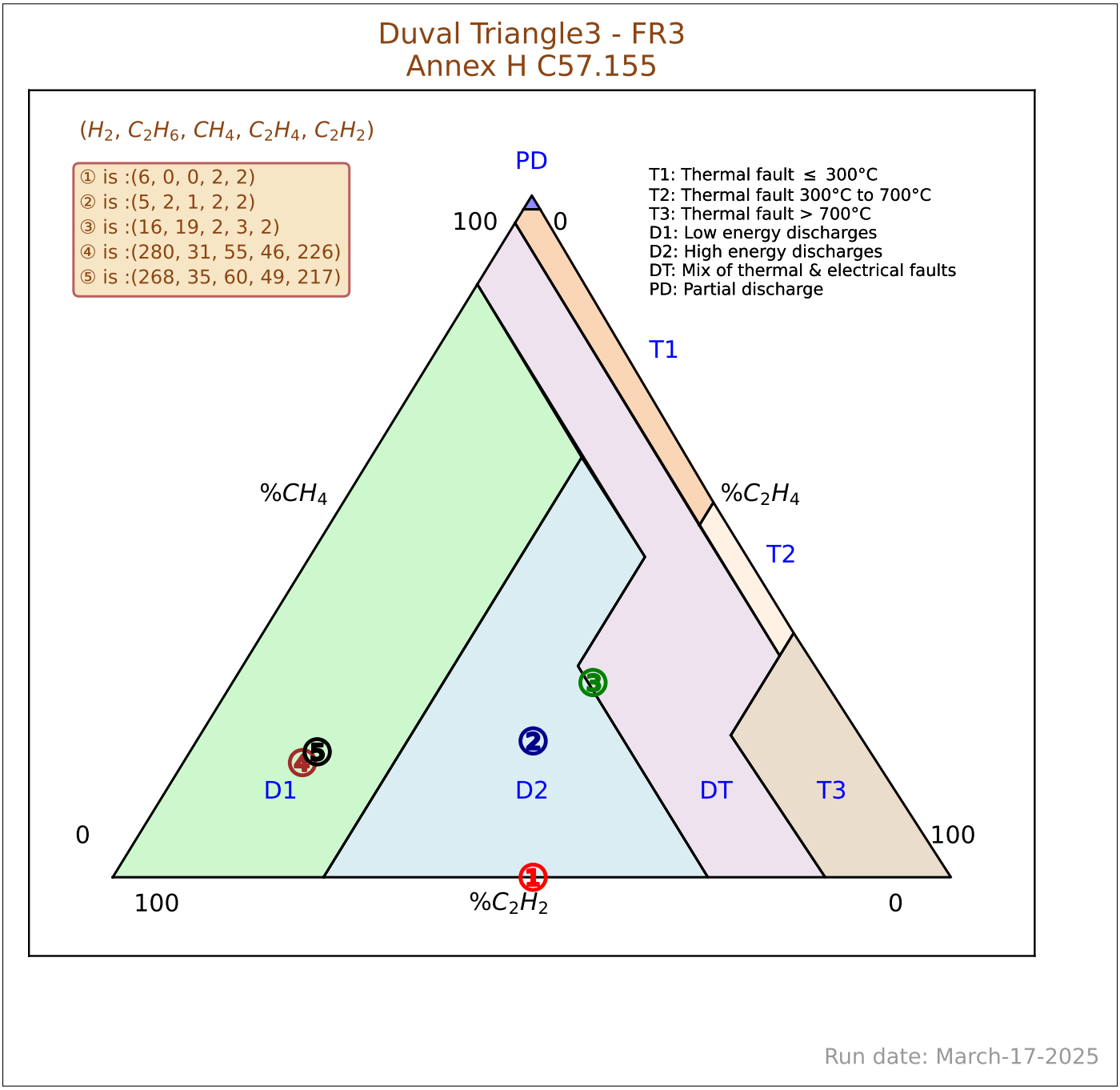


Figure 10: The mineral oil fault zones presented by use of the Duval Triange 1 from reference [3] with fault codes identified.

## 5 Description of Solutions - Silicone Filled[7]

Since its introduction in 1974, silicone dielectric liquid was used as a less flammable insulating liquid option for small power and distribution transformers. Silicone liquids used in transformers are considerably different in composition than mineral oils. Although many of the gases generated under thermal and electrical stress are the same for mineral oils and silicone liquids, there differences in proportions of these gases with a substantially larger quantities of carbon oxides seen in typical silicone transformers can be considered as a noticeable distinction. In addition each gas has a different solubility in silicone liquid than in mineral oil.

## 6 Silicone Oil Analysis

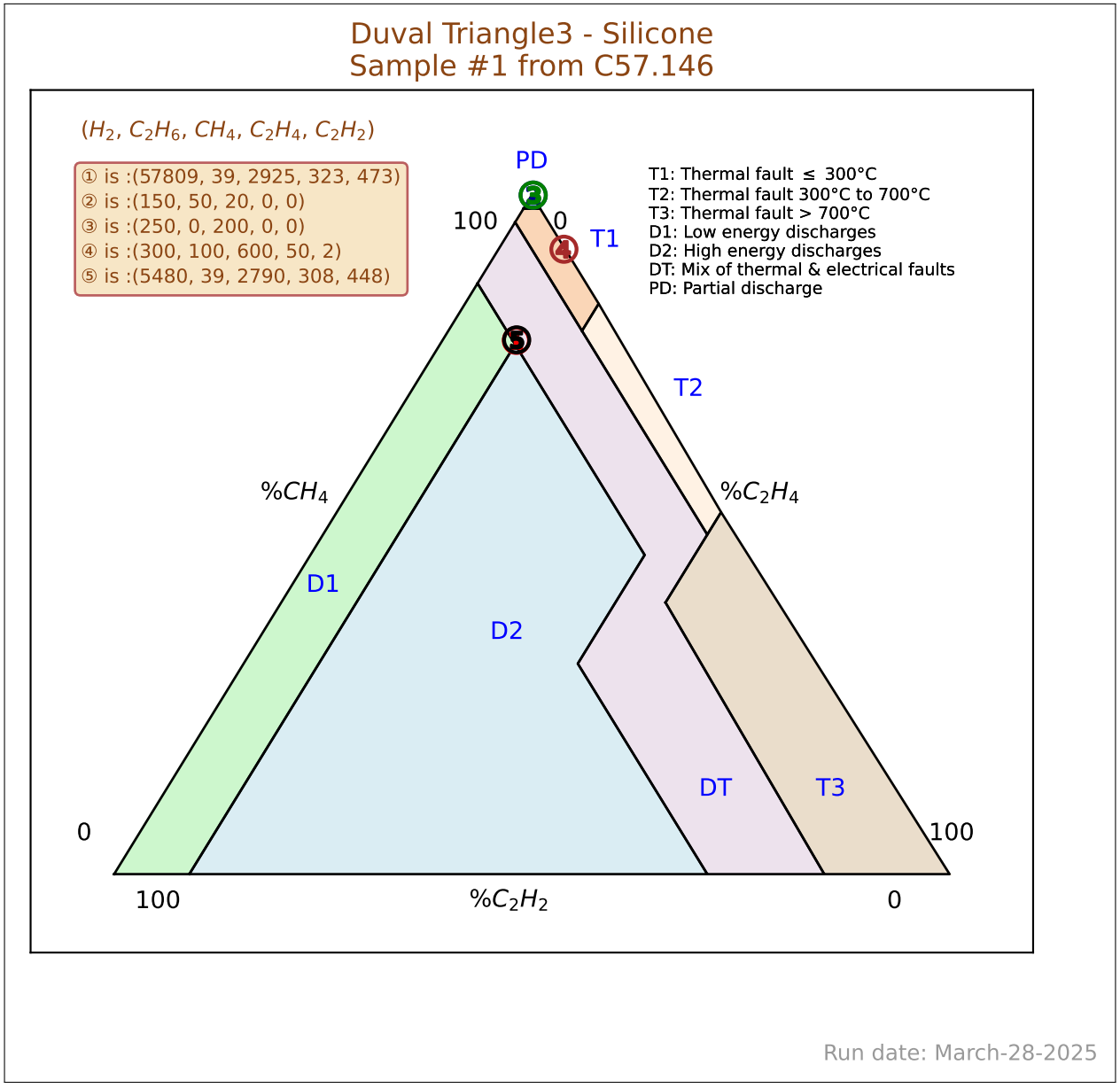


Figure 11: The silicone oil fault zones presented by use of the Duval Triange 3 from reference [7] with fault codes identified.

## 7 Closing Comments

The primary use of dissolved gas analysis (DGA) is as a routine monitoring insulating fluid test for electrical equipment. Incipient fault conditions - disruptions in the normal electrical and mechanical operation of electrical equipment - cause the fluid to break down, generating combustible gases. The profile of those gases can be interpreted to diagnose whether fault conditions exist, and how severe those faults may be.

This article shares a look at the Duval Pentagon and Duval Triangle as an approach to dissolved gas analysis in the fluid. As experience as grown from inspections of field installed transformers, new insights to improvements of the methods has improved. There are many other techniques including CO, CO2, and furans that further permit earlier detection of faulty transformers. When using analysis tools there are two important statements about dissolved gas analysis. The first is a theshold level is needed to make a more accurate assessment! As with the Pentagon and Triangle, a solution is always presented but unless the theshold is reached, a misinterpretation can be made. The second is to use more than one method or tool. As the references in this article provide, several techniques are preferred. Use of the pentagon and triangle is only one comparison that can be used. The use of DGA results to monitor transformers should not be assumed to be a replacement for other prudent operating, management, and monitoring practices. Conclusions or actions should never be based exclusively on a single DGA result.

## References


[1] IEC.*IEC 60599–Mineral Oil-impregnated Electrical Equipment in Service - Guide to Interpretation of Dissolved and Free Gases Analysis;* International Electrotechnical Commission: Geneva, Switzerland; 2015.

[2] IEEE.*IEEE C57.104-2019–Guide for the Interpretation of Gases Generated in Mineral Oil-Immersed Transformers;* Institute of Electrical and Electronics Engineers: New York, NY 10016-5997, USA; 2019.

[3] IEEE.*IEEE C57.155-2014–IEEE Guide for the Interpretation of Gases Generated in Natural Ester and Synthetic Ester-Immersed Transformers;* Institute of Electrical and Electronics Engineers: New York, NY 10016-5997, USA; 2014.

[4] Luiz Cheim, Michel Duval, Saad Haider *Combined Duval Pentagons: A Simplified Approach.* Energies 2020, 13, 2859; 2020.

[5] C. Beauchemin, THH2b Analytical Services Inc. *DGA Tools: Duval Triangles and Pentagons.* www.nist.gov/dads/HTML/hammingdist.html; April, 2017.

[6] C. Xiang, Q Zhou, J. Li, Q. Huang, H. Song, Z. Zhang *Comparison of Dissolved Gases in Mineral and Vegetable Insulating Oils under Typical Electrical and Thermal Faults.* Energies 2016, 9, 312; 2016 2019.

[7] IEEE.*PC57.146/D2–Draft Guide for the Interpretation of Gases Generated in Silicone-Immersed Transformers.* Institute of Electrical and Electronics Engineers: New York, NY 10016-5997, USA; 2025.


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